

controlling forging tests, and to the hardening of iron and steel. Under the last head experiments were made to ascertain the influence of the percentage of carbon on the hardening capacity, the hardening effect of different quenching liquids, the influence of the temperature of the quenching liquid on the hardening result, the influence of different hardening temperatures. Other researches described dealt with an attempt to ascertain the homogeneity of iron and steel, the degree of annealing, the influence of cold-working, determination of the yield point, ultimate stress and elongation, and tests of blanks for gun barrels.

Prof. E. D. Campbell gave the results obtained at the University of Michigan during the past three years in investigating the heat of formation of the compounds of iron with carbon and silicon.

Mr. Axel Sahlin described a water-cooling device introduced by himself for protecting the walls of the lower part of the blast furnace.

Mr. J. M. While submitted a description of the new Bessemer shop and heating pits at the Barrow Hæmatite Steel Company's works. The results obtained are of interest as showing that the faster working in vogue in the United States cannot be introduced into England with advantage, for the same conditions do not apply in each country.

Mr. H. E. Wimperis, acting on a suggestion from Prof. Ewing, measured Young's modulus for a long rod by tension in an ordinary testing machine, and compared the value thus obtained with that found by experiments on pure bending. The two values differ slightly from each other, but such differences as are found may be regarded as indicating that there is no internal sliding due to layers of any impurity that may be contained in the metal.

Mr. Bennett H. Brough, the secretary, described a medal presented to the Institute by Mr. E. J. Ljungberg. It was struck in steel from the Domnarfvet Steelworks, Sweden, and is the first medal that has ever been struck in that metal. The soft basic Bessemer steel of which the medal is made contained: carbon, 0.05; manganese, 0.19; silicon, 0.007; phosphorus, 0.002; sulphur, 0.005.

Baron H. von Jüptner submitted a paper on iron and steel from the point of view of the phase-doctrine, in which he controverted some of the views elicited by the publication of the paper by Bakhuis-Roozeboom last autumn. He deals chiefly with the state of equilibrium between martensite and graphite.

The next meeting of the Institute will be held in Glasgow in September.

VITRIFIED QUARTZ.¹

ALTHOUGH the great improvements introduced into the art of glass making by Abbe and Schott have led to marked advances in microscopy, in thermometry and in other departments during the last quarter of a century, glass is still unsuitable for many of the purposes to which we put it, and there remains a real need for some plastic material more infusible, more insoluble, more fully transparent, more elastic and more stable under changes of temperature than glass.

Such a substance exists in the form of vitrified quartz, or vitrified silica as I shall prefer to call it. Vitrified silica was first made in 1839 (*Comptes rendus*, viii. 678, 711) by M. Gaudin, who spun threads of it by hand and noticed their flexibility; and made small, very hard pellets of it by dropping fused quartz into cold water, and observed that in this form it was inactive to polarised light.² It was rediscovered in 1869 by M. Gautier (*Comptes rendus*, cxxx. 816), who made capillary tubes and spirals of vitreous silica and exhibited them at the Paris Exhibition in 1878, but who failed to obtain larger objects even with the aid of the electric furnace. Finally it was discovered yet once again, in 1889, by Prof. C. V. Boys, who used the torsion of "quartz fibres" for measuring small forces and produced fine tubes and small bulbs of the same material, and who was the first to fully recognise the great value of this remarkable substance.

As all who are here to-night are not chemists, I may remind you that quartz or rock crystal has for some time past been

used by spectacle makers and in the construction of optical instruments; and that it is a form of oxide of silicon¹ which is very familiar to us all in the forms of sand and flint. Quartz is occasionally found in magnificent masses, but our chief source of supply is Brazil, where it occurs in large fragments like those before us on the table.

Quartz itself exhibits many of the desirable qualities enumerated above. It is hard, transparent to the ultra-violet rays, difficult to melt, a good insulator, and insoluble in most solvents, but it bears sudden changes of temperature very badly, and therefore it is not easy to manipulate quartz at high temperatures. When it has been vitrified by heat, however, it becomes much more tractable, and in the vitrified state (vitrified silica) it is not very difficult to deal with.

It is about this "vitrified silica," how to prepare it and fashion it into apparatus when plastic, and about its properties and uses that I am about to address you to-night.

The first obstacle met by those who wish to obtain vitrified silica is caused by the tendency of quartz to splinter. It will not bear contact with a flame. As you see, when a piece of quartz is thrust into a flame it cracks and falls to pieces, and the fragments again break up when similarly treated. Consequently, it was very difficult for the pioneer workers to soften their quartz in the flame. It is true that if the quartz be broken small and heated to redness in a crucible it becomes more easy to manage, but even then it gives trouble, and I should not like to say how much my first silica tube, which held about 5 c.c., had cost me for oxygen and labour when it was finished.

Fortunately we have found that we can prevent the splintering of quartz by heating it in small fragments to about 1000° C. and throwing it quickly into cold water. As you see, when this is done the quartz becomes white and enamel like, and after the treatment has been repeated the product, though still in masses, will not splinter to the slightest extent if it be thrust suddenly into the hottest part of an oxy-hydrogen flame. The preparation of this non-splintering silica constitutes the first stage of the process we are about to show you.

Another difficulty is connected with the oxy-gas burner. Vitrified silica only becomes sufficiently plastic for our purpose when it is above the melting point of platinum; and it cannot be heated sufficiently in all parts of an oxy-gas flame. What is wanted is not so much a very large flame as one which presents a very hot spot (this is situated just beyond the inner blue cone of the flame). After trying all sorts of burners I have concluded that the "mixed gas" jets give the best results, and of the burners I have tried the injector burner of Mr. Jackson, of Manchester, is decidedly the best I have met with.

The first step in the process of converting the white enamel like non-splintering silica into tubes and other vessels consists in pressing together the ends of two small fragments of the solid held in platinum forceps till they adhere, adding a third lump, then a fourth, and so on until a rough rod has been made. This rod is afterwards reheated and drawn out into finer rods about 1 mm. in diameter. In doing this care must be taken to heat each fresh mass of material slowly and from below upward in order that there may be as few bubbles as possible in the product.

A few of the fine rods of silica are next bound round a stout platinum wire, or twisted into a spiral while soft (Boys' and Dufour's method), and heated in the flame till their sides adhere. The uncouth tube thus produced is reheated, drawn out and closed at one end, a bulb is blown on the closed end in the usual manner, and this, when again drawn out, gives us a fine and fairly regular tube which can be lengthened by adding silica to one end of it, blowing a new bulb from this and drawing it out as before.

The enlargement of the small bulbs was rather difficult at first. My earliest attempts consisted in adding small lumps of silica to one end of a bulb, softening them in the flame and expanding the bulb by blowing. It is not impossible to succeed in this way, though the vessels so produced are apt to be uncouth in appearance. But the process is unsatisfactory owing to the fact that often the thinner parts of a bulb immediately surrounding the mass to be expanded become hotter and softer than the latter. When this happens the bulb bursts, and as it can only be repaired by the addition of fresh lumps of silica the process is apt to be tedious and expensive. After many failures, it occurred to me that I might develop the bulbs by applying thin rings of silica as shown in Fig. 1, heating them until the silica begins to spread

Silicon was discovered by Berzelius in 1823.

¹ A discourse delivered at the Royal Institution, on March 8, by W. A. Shenstone, F.R.S.

² A recent observation made by Prof. S. P. Thompson confirms this.

and then expanding them by blowing. This method gave satisfactory results at once. By it we can produce long tubes and other apparatus like those exhibited to-night, if not at a very quick rate or very low cost, yet with certainty and very much more quickly than before.

When a tube of silica has been made it can be worked in the flame as easily, though not as inexpensively, as glass. Such a tube can be thickened readily by adding fresh rings of silica; it can be drawn out to various degrees of fineness and sealed hermetically; whilst all kinds of joints can be made easily. In one respect silica is easier to work than glass. It never breaks when thrust into the flame, and finished apparatus needs no annealing.

One precaution must be taken. The eyes must be protected by black spectacles. The glass of which these are made must



FIG. 1.

be very dark; so dark that white hot silica does not look very bright when viewed through it.

I have spoken of silica as being easy to work. I do not mean you to understand, however, that it is easy to do what you see Mr. Lacell doing to-night. It is not easy to perform any operation of this sort with his wonderful precision, and especially it is not easy to work under the conditions enforced upon him to-night, for he can see nothing of the effects he produces and must adapt his manipulations to my remarks although he can hear the latter only very imperfectly.

The Properties and Applications of Silica.

Vitrified quartz is harder than felspar, but less hard than chalcedony. When cut with a file it breaks like glass. Its conducting power for heat is about equal to that of glass. Mr.

telier (*Comptes rendus*, cxxx. 1703) and more recently by Prof. Callendar. The former finds its mean coefficient of expansion between 0° and 1000° to be 0.0000007, but from the manner in which his material was prepared I think it is probable that it was not quite pure. Prof. Callendar has, within the last few days, examined the behaviour of a rod of pure vitrified silica prepared by my method. He finds its mean coefficient of expansion to be only 0.00000059, which is only $\frac{1}{7}$ as great as that of platinum, and much smaller than that of any other similar substance that has hitherto been studied. He finds also that the expansion of vitrified silica is exceedingly regular up to 1000°, and that if not heated above 1000° the rod returns very exactly to its original length when cold. Beyond 1000° he found a slight permanent elongation, although the rod was under compression. Prof. Callendar was able to carry his experiments up to 1500°, which is very satisfactory, for it shows that vitrified silica remains solid, or practically solid, at this very high temperature. This is an important observation, as less carefully conducted experiments had led us to fear that it became slightly plastic even at as low a temperature as 1000°. Above 1000° the rate of expansion diminishes rapidly, changing to a contraction at about 1200°. On cooling from 1500° to 1200° it expands.

Fine rods of silica and also quartz fibres are apt to become rather brittle after being heated to redness. But we have not at present detected this defect in the case of thick tubes or rods.

The transparency of vitrified silica to the ultra-violet rays has been carefully examined by Dr. A. Wynter Blyth, to whom I am greatly indebted.

The following figure (Fig. 2) illustrates very well the character of the results he has obtained. This figure gives the results of photographing electric sparks taken between electrodes made of an alloy of mercury, tin, zinc and cadmium after passing the light through sheets of quartz, vitrified silica, soda glass and flint glass. The plates of the last three substances were of equal thickness and were carefully prepared for me by Mr. Hilger.

The results show, as indeed we have found by actual experi-

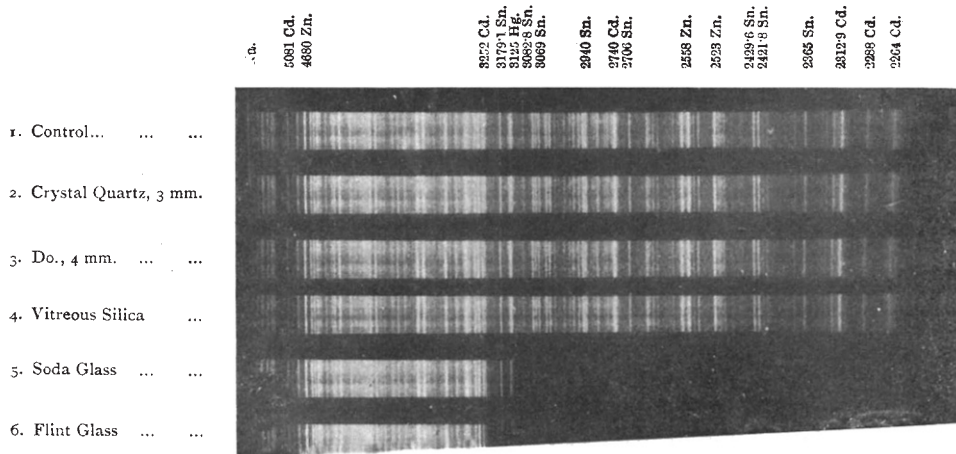


FIG. 2.

Boys has shown that, even in an atmosphere saturated with moisture, it is a very good insulator. Its density (2.21)¹ is decidedly less than that of quartz (2.66). Its optical properties have not yet been fully studied, but its approximate index of refraction has been determined by Prof. S. P. Thompson by means of a small prism cut for the purpose by Mr. Hilger. It is decidedly less than that of quartz.

The melting point of silica is not known and it is plastic over a considerable range of temperature. When a platinum wire embedded in a thick tube of silica is heated from without by means of an oxy-gas flame, the platinum melts and runs at a temperature at which the silica retains its shape.

Its rate of expansion has been studied first, by H. Le Cha-

¹ This was determined by my pupil, Mr. T. Pears, the silica used contained a few minute bubbles.

ment, that silica tubes are much more suitable than glass ones for use in studying the spectra of electric discharges.

The most remarkable property of vitreous silica is its behaviour under sudden changes of temperature. We have seen already that tubes of it may be plunged suddenly into an oxy-gas flame without injury, and I have mentioned the fact that apparatus made of silica needs no annealing. But this is not all; we may drop water on a white hot vitrified silica rod, or plunge white hot silica into cold water, or even, by Prof. Dewar's kind aid, into liquid air without injuring it in any way whatever; indeed, experiments seem to show that the material gains very distinctly in regard to its elasticity when it is thus treated. I need hardly point out how convenient tubes of such a material will be to

¹ Le Chatelier's curve, see Fig. 3, shows a similar contraction, but commencing at a somewhat lower temperature.

chemists, or how many spoilt lecture experiments may be avoided in future by those who possess a silica tube.

This last property of silica and the splintering of quartz find an explanation in the results obtained by Le Chatelier (*Comptes rendus*, cviii. 1046, and cxxx. 1703) and by Callendar. These, as already explained (Fig. 3), show that its rate of expansion is exceedingly low, and, moreover, that at temperatures much above 1000° it contracts when heated. In these circumstances it follows, first, that the strains set up in silica when it is suddenly heated or cooled are comparatively small in amount, and, secondly, that if, for example, vitrified silica be suddenly cooled from 1500° to temperatures below 1000°, the strains set up at the earlier stages of the change must tend to neutralise those produced subsequently. These facts enabled Le Chatelier to predict, a little while ago, the indifference of vitrified silica to sudden change of temperature. But the phenomena had been observed previously and exhibited in this country.

The behaviour of quartz under changes of temperature is also peculiar. This was studied by Le Chatelier in 1889 (*Comptes rendus*, cviii. 1046). From his curves, which are given in Fig. 3, it may be seen that this form of silica expands quite regularly, and much more rapidly than vitreous silica up to 570°, but that at that temperature a sudden expansion takes place which is followed by a steady contraction on further heating.

One of the most important fields in which vitrified silica is likely to be useful is that of thermometry.

Owing to the small coefficient of expansion of vitrified silica the degrees of silica-mercury thermometers will be of greater length in proportion to the volumes of the bulbs than those of

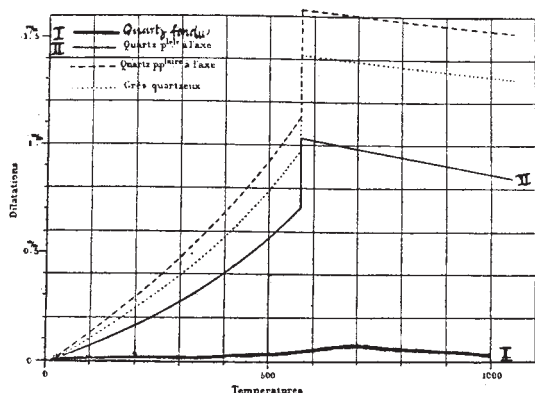


FIG. 3.

glass instruments. Owing to its high melting point it should be possible to employ it with advantage for measuring high temperatures by replacing the mercury by tin or some other metal, as has been done by M. Dufour (*Comptes rendus*, cxxx. 775). And whilst the great elasticity of vitrified silica suggests that the zero points of silica-mercury thermometers will be much more stable than those of glass instruments, the impunity with which it may be suddenly cooled from high temperatures promises obvious advantages.

Finally, the high melting point of silica should make it very valuable for use in platinum thermometers, and I exhibit such a thermometer to-night which has been fitted up for Dr. R. T. Glazebrook. But as the applications of vitreous silica to thermometry are still under investigation I will not dwell on this part of the subject except to add that, as glass reservoirs for air thermometers have proved disappointing, I am not without hopes that the new material may prove helpful in that department also.

We have not yet had time to examine the behaviour of silica with solvents, but if it acts like other forms of the same compound, it may be expected to replace platinum for some purposes, as, for example, for condensers for the preparation of pure water, and vessels of silica probably would be much more suitable for use in exact experiments on the freezing points and boiling points of many dilute solutions than the glass tubes now often used for such work. But, of course, silica vessels would be very susceptible to the action of alkalis. Finally, silica may be expected to prove superior to glass for use in researches on pure

gases, owing to the qualities of its surface, and in experiments concerning the behaviour of gases at high temperatures. We have already one small application of silica to research in this latter field to put upon record. It is well known that nitrogen and oxygen enter into combination under the influence of the silent discharge, and Sir William Crookes (*Chem. News*, lxx. 301) has shown that oxides of nitrogen are present in considerable quantities in the flames which accompany the electric discharges of large induction coils; but although various observers have reported indications of the presence of nitrous fumes in the neighbourhood of flames, the forming of an oxide of nitrogen from oxygen and nitrogen alone, and without the intervention of electricity, has not, so far as I am aware, been unmistakably established. Therefore it is interesting to record the fact, first observed by Mr. Lacell, that nitric peroxide may be produced by heating a mixture of oxygen and nitrogen above the melting point of platinum in tubes of silica. It is easy to obtain a gas showing a distinctly yellow colour and exhibiting the reactions of nitric peroxide in this way.

Of course vitreous silica is not entirely without defects. Unfortunately it becomes slightly permeable to hydrogen, as platinum does, though to a less extent (Villard, *Comptes rendus*, cxxx. 1752), at about 1000°. It is attacked when hot by alkaline oxides. It may be heated to about 960° in contact with copper oxide without injury, but at higher temperatures it is attacked. It may be heated more strongly with ferric oxide, but quicklime attacks it at a bright red heat. It is evident that caution must be exercised when it is employed with basic oxides or alkaline solutions. When one first fashions vessels of silica before the flame the vessels exhibit to a greater or less extent a phenomenon resembling devitrification. They become covered with a white opaque crust. This is easily removed by reheating, provided that the tube has been kept scrupulously free from dust and dirt during the process of making it. If this be not done the appearance of the vessel may be spoilt permanently. The earlier observers attributed this phenomenon to the volatility of silica. My impression is that it is connected with the minute traces of alkaline metals present in most Brazil pebble which are usually burnt off in the processes I have described. From what I have told you to-night you will see that in several respects vitrified silica is as much superior to the best glass as Jena glass is superior to more ordinary specimens, and that the progress made in the last few years will make it possible for investigators to employ vitreous silica much more widely in the future than has been possible in the past. At the same time it is evident that the processes for producing vitreous silica are still in their infancy, that there is much more to be done and that further progress can only be made at considerable expense.

In concluding my remarks I wish to express the great obligation I am under to my friend Mr. Lacell. You will have discovered for yourselves that the chief burden has been upon his shoulders to-night, and that without the illumination provided by his precise and beautiful manipulation my discourse would have been but a dry affair. Also I must add that the cost of the work at its later stages has been aided by a subsidy from the Government Grant Fund of the Royal Society.

NOTES FROM RECENT CONSULAR REPORTS.

A REPORT on German East Africa, by Mr. A. C. Hollis, acting vice-consul at Dar-es-Salaam, and one on Veterinary Work in British East Africa and Uganda Protectorates, by Mr. R. J. Stordy, have recently been published as Nos. 2568 and 551 of the Foreign Office Series. The following notes from the reports refer to matters of scientific interest:—

GERMAN EAST AFRICA.

Locusts.—Great interest was shown in the success of the discoveries made at the Grahamstown Bacteriological Institute in the destruction of these insects, and a small quantity of "locust fungus" was imported, and has since been used on Kilima Njaro and in Usambara with success.

Caoutchouc.—There are numerous sorts of caoutchouc creepers and trees indigenous to German East Africa, but the only kinds which are of value are *Landolphia Kirkii* (Kiswahili, *Mohango*), and *Mascarenhasia elastica* (Kiswahili, *Mgora*). Until quite lately it was believed that the best rubber was the product of *Landolphia florida* var. *Comorensis* (Kiswahili, *Mbungo*), but it has now been proved that this creeper is practically worthless.

Samples of the milky juice of the wild fig tree have been sent